(e)ISSN 2656-8896 (p)ISSN 2656-890X
Journal of Infrastructure and Facility Asset Management – Vol. 6,Special Issue 2, January 2024

Correlation of Initial Soil Density and Maximum Soil Density Under Drying-Wetting Cycles and Their Soil Erodibility

Tia Evriana[1,a], Trihanyndio Rendy Satrya[2,b], Mahendra Andiek Maulana[2,c) & Wahyu Supriyo Winurseto[3,d]

[1)]Magister Student, Civil Engineering Dept, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
[2)]Civil Engineering Department, Institut Teknologi Sepuluh Nopember, Surabaya, Indonesia
[3)]Banten BPJN, Directorate General of Highways, Ministry of Public Works and Public Housing, Serang, Indonesia
Correspondent : [a)]tia.evriana@pu.go.id, [b)]trendysatrya@gmail.com, [c)]mahendrasipil@gmail.com & [d)]winurseto@pu.go.id

ABSTRACT

The Serang - Panimbang Toll Road plan area of Banten province in regional stratigraphy from the starting station to the end consists of sedimentary rock sediments of the Bojongmanik Formation in the form of sandstone intersections with clayey limestone inserts that have been precipitated by the products of Karang volcano consisting of breccia and lava. This volcanic material exhibits a coarse soil texture, high water absorption capacity, and susceptibility to erosion. Soil erosion levels can be determined by measuring soil erodibility. Erosion often occurs in Indonesia because Indonesia has a tropical climate which has two seasons, the rainy and dry seasons. This climatic pattern contributes to the soil vulnerability to erosion, impacting its density. Therefore, it is important to know the effect of drying-wetting cycle on erodibility along the slope of Serang-Panimbang Toll Road. Soil samples will be modeled under two density variations: initial density and maximum density. Drying-wetting tests will determine the physical, mechanical, suction, and erodibility properties of soil. The results showed that there was an increase in the degree of saturation of 8.31% for the initial density soil and 17.12% for the maximum density soil. Unconfined compressive strength of the soil with initial density and maximum density also decreased in consistency which decreased from very stiff and stiff to very soft. However, erodibility values for both density conditions remained constant at 0.19 despite the drying-wetting cycles and is classified as low.

Keywords : erodibilty, soil density, drying-wetting, suction

INTRODUCTION

Infrastructure is constructed to serve the population in a particular area (Suprayitno & Soemitro, 2018). It plays a vital role in enhancing the quality of life within a region and throughout the country. As a result, maintaining infrastructure in optimal functional condition is crucial. This involves adherence to the fundamental principle of infrastructure asset management (Maulidha et al., 2022). Recognizing the importance of this infrastructure, the construction of the Serang-Panimbang Toll Road is currently ongoing in Banten province. This toll road is set to connect four districts and cities within the province. The proper operation of infrastructure is one

(e)ISSN 2656-8896 (p)ISSN 2656-890X
Journal of Infrastructure and Facility Asset Management – Vol. 6,Special Issue 2, January 2024

of the prerequisites that must be fulfilled for infrastructure to function effectively (Soemitro & Suprayitno, 2020). The presence of the Serang-Panimbang Toll Road promises numerous conveniences, as roads stand as integral components of land transportation infrastructure. The ongoing road construction emphasizes the importance of ensuring adequate material availability (Widayanti et al., 2019).

In this context, geotechnical mapping in accordance with Infrastructure Asset Management principles, assists in the planning, design and feasibility study of the Serang-Panimbang Toll Road infrastructure project to ensure its success. During the design process, the stability of infrastructure is often assumed to be static and is considered by applying factors of safety generated by extreme condition analysis. Nevertheless, there has been a lack of consideration for the variability of natural factors, and notably, the growing risk posed by extreme environmental conditions resulting from global climate change (Satrya et al., 2019). At the construction of the serang-panimbang toll road, it is necessary to consider changes in soil characteristics in climate change in Indonesia.

The planned area of the Serang-Panimbang Toll Road at Banten province, in terms of regional stratigraphy, comprises sedimentary rock deposits from the Bojongmanik Formation. It manifests as a mixture of sandstone with clayey limestone inserts (Tmb) dating back to the Early Miocene period. Above these deposits lies the Banten Tuff (Qpvb), composed of tuff, pumice tuff, and tuffaceous sandstone. On top of the Banten Tuff, there is the deposition of materials from the Karang volcano, comprising breccia and lava.

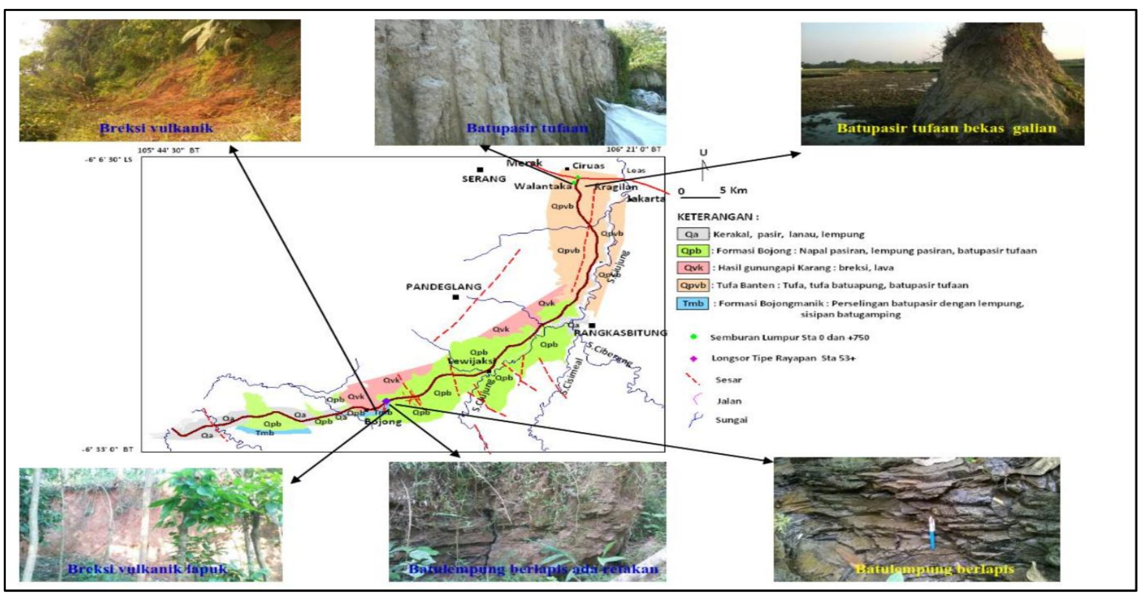


Figure 1. Regional Geological Conditions of Serang-Panimbang Toll Road
Source : PPK Serang-Panimbang Toll Road

This volcanic product has a coarse soil texture, has properties sensitive to soil erosion, is grayish in color, tends to be loose, has a high water-absorbing ability and erosion is easy to occur. Soil erosion is the process of moving parts of soil from one place to another (Arsyad, 2010). The high erosion that occurs is also directly linked to the level of soil density. The higher soil density of a land, the greater the erosion will be until a certain optimum point then the erosion will decrease (Sucipto, 2007).

The level of soil erosion can be known by measuring soil erodibility. Soil erodibility (soil sensitivity to erosion) is largely determined by soil resistance to external forces and high water-absorbing ability (Utomo, 1994). Factors that affect soil erodibility are organic content, soil structure, soil texture, and soil permeability.

Indonesia has a tropical climate which has two seasons, the rainy and dry seasons, it can affect soil properties. The repetition of this cycle can make the physical capacity of soils that are initially resistant to erosion become more vulnerable or sensitive to erosion. In this process the soil undergoes mechanical and chemical weathering relatively quickly compared to subtropical regions. Rocks or soils experience fatigue and this causes the soil's ability to withstand the kinetic energy of rainwater to decrease, making it vulnerable to erosion. (Asmaranto et al., 2010).

Based on the background, the influence of tropical climate or changes in drying and wetting cycles on soil can affect the physical, mechanical and hydraulic properties of soil. Differences in soil density can also affect changes in erosion rates. Therefore, it is necessary to model the rainy season and dry season with drying-wetting to determine the effect of soil erodibility values in dry and wet conditions, and their correlation with variations in soil density on slopes on the Serang-Panimbang toll road.

LITERATUR REVIEW

Soil Erosion

Naturally, soil erosion stands as one of the most common causes of landslides. Erosion is the process of soil loss or displacement from one area, carried away by water or wind to another location. Soil erosion can occur due to natural phenomena and human activities. However, generally, the primary cause of soil erosion is natural, involving the movement of water, wind, and the characteristics of rainfall (Aizid, 2021 in "Tanah Longsor & Erosi Book," 2012).

Efforts to forecast soil erosion rates often employ the USLE (Universal Soil Loss Equation) model (Wischmeiere & Smith, 1978). Within the USLE model, one determinant of the soil erosion rate is the soil erodibility value (K) (Arsyad, 2010; Asdak, 2010). One method entails utilizing the nomogram created by Wischmeier in 1971.

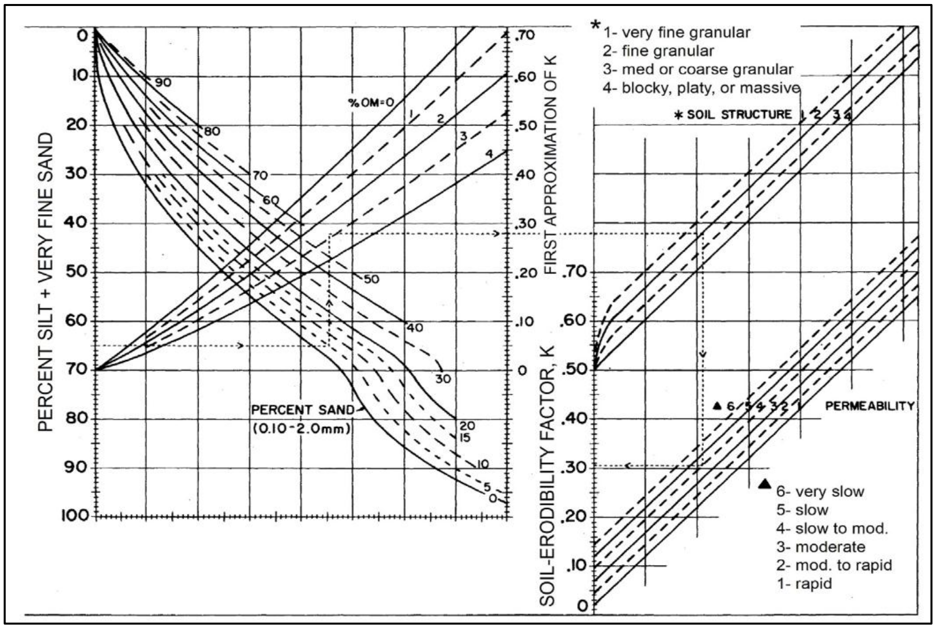


Figure 2. Nomogram to Calculate Erodibility Factor (K)
Source : Wischmeiere, 1971

Where in the description for soil structure and permeability codes as shown in **Table 1** and **Table 2**.

Table 1. Soil Structur Code

Soil structure class (diameter size)	Code
Very fine granular (< 1 mm)	1
Fine granular (1 to 2 mm)	2
Medium - coarse granular (2 to 10 mm)	3
Block-shaped, slab, massive	4

Source : Hardiyatmo, 2012

Table 2. Permeability Code

Permeability class	Speed (cm/hr)	Code
Very slow	< 0,5	6
Slow	0,5 – 2,0	5
Slow to medium	2,0 – 6,3	4
Medium	6,3 – 12,7	3
Medium to fast	12,7 – 25,4	2
Fast	> 25,4	1

Source : Hardiyatmo, 2012

Unsaturated Soil

According to Soemitro and Warnana in the book 'Karakteristik Tanah tidak Jenuh' (2020), the categorization of saturated and unsaturated soils requires separate consideration due to differences in natural conditions and technical behavior. Besides that, unsaturated soil exhibits characteristics such as soil suction and positive air entry value. This soil position lies within the desaturated surface, resulting in suction (unsaturated soil).

While direct measurement allows determination of unsaturated soil properties, it is time-consuming and expensive. Consequently, numerous 'estimation techniques' based on unsaturated soil properties have been explored in research conducted in various countries (Vanapalli et al., 1996; Delwyn G Fredlund (2002).

SWCC (Soil-Water Characteristic Curve) data serves as a basis for calculating the necessary function representing unsaturated soil characteristics. Information regarding SWCC can also be derived from soil property classifications, correlations, or databases containing previous laboratory soil test results.

Permeability Coefficient

Various experts have presented several theories regarding the calculation of the permeability coefficient of unsaturated soil. (Muntaha, 2010).

Fredlund and Rahardjo (1993) state that soil-water characteristic curves (drying or wetting curves) can be utilized to compute the permeability coefficient kw (θw) of unsaturated soil. Campbell (1973) developed an empirical equation to determine the unsaturated soil permeability coefficient (kw) as follows:

$$Kw = Ks \frac{(\theta w)\ 2b+3}{\theta s} \qquad \ldots(1)$$

With :

$$b = \frac{\Delta log\psi}{\Delta log\theta w} \qquad \ldots(2)$$

Where :

kw = coefficient permeability unsaturated soil
ks = coefficient permeability saturated
θw = volumetric water content
θs = volumetric water content saturated
ψ = suction

Drying-Wetting Process

The drying process is a condition in which the water content within the pores of soil/rock decreases. Conversely, in the wetting process, there is an increase in the water content within the pores of a mass of soil/rock (Ariesnawan, 2015). Repeated drying and wetting cycles can impact the soil physical and mechanical properties. The correlation between the drying and wetting curves is between volumetric water content and matric suction. The formula to obtain volumetric water content and suction is as follows: (Fredlund & Rahardjo, 1993).

$$\theta = \frac{SVv}{V} \qquad \ldots(3)$$

Where :
Θ = volumetric water content
S = degree of saturation
Vv = void volume
V = soil volume

For Log Suction obtained from the following formula Fredlund and Rahardjo (1993) :

Log Suction (kPa) = 5,327-0,0779Wf …(4)

Where :

Wf = Watercontet Filter Paper

RESEARCH METHOD

To conduct this research, it's necessary to test the physical, mechanical, and suction characteristics of the soil subjected to drying-wetting cycles. Soil samples will be modeled in two density variations: initial density and maximum density. Utilizing these initial soil parameters, the water content under saturated conditions can be determined. Similary, from the proctor maximum density condition. Furthermore, the samples will be prepared for the wet-drying test by adjusting the moisture content to 25% of the divergence of saturated water content and air-dry water content.. The drying-wetting cycle will be conducted once. Observations will be made on the physical, mechanical, suction, and erodibility properties resulting from the drying-wetting test.

DATA COLLECTION

In this study, soil sampling was conducted at the Serang-Panimbang toll road plan at STA 57+175. The collection of disturbed and undisturbed soil samples was performed at the slope surface. The number of samples collected is as follows:

1. Disturbed soil samples totaling approximately 150 kg.
2. Undisturbed soil samples consisting of 2 shelby tubes.

Physical property testing included sieve and hydrometer analysis, volumetric-gravimetric testing, and consistency testing. Mechanical testing encompassed standard Proctor compaction, unconfined compressive strength, and erodibility testing.

RESEARCH ANALYSIS

The results of the research that has been conducted of the soil properties test, the surface layer soil sample taken from STA 57+175 at a depth of -4 m with the results classified according to USCS as CH and according to AAHSTO classified A-7-6. The value is shown in the in Table 3.

Table 3a. Soil Properties

No	Parameters	Symbols	Units	Value
1	**Soil Physical**			
a	Sieve Analysis & Hydrometer			
	Gravel		%	**2,15**
	Sand		%	**8,71**
	Silt		%	**19,29**
	Clay		%	**69,86**
b	Atterberg Limit			
	Liquid Limit	LL	%	**68,67**
	Plastic Limit	PL	%	**24,76**
	Plasticity Index	PI	%	**43,91**

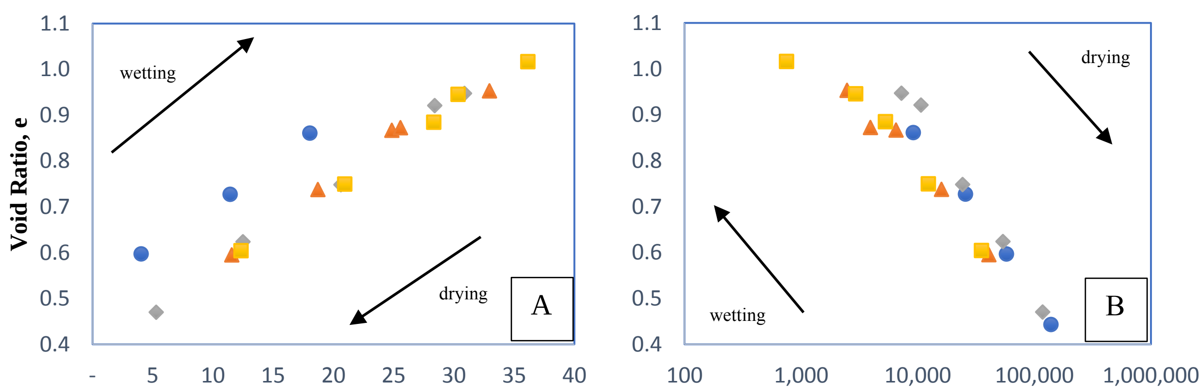
Table 4b. Soil Properties

No	Parameters	Symbols	Units	Value
c	Volumetri Gravimetri			
	Water Content	W	%	**30,900**
	Specific Gravity	Gs		**2,615**
	Dry Density	γd	gr/cm^3	**1,344**
	Void Ratio	e		**0,946**
2	**Soil Mechanical**			
a	Unconfined Compressive Strength	qu	kg/cm^2	**2,35**
	Cohesion Undrained	Cu	kg/cm^2	**1,17**
b	Density			
	Maximum dry density	γd max		**1,405**
	Optimum water content	w max		**24,66**
3	**Soil Classification**			
	USCS			**CH**
	AASTHO			**A-7-6**

Source : Author, 2024

Influence of Drying-Wetting on the Parameters of Soil Physical Properties

Figure 3 show a combined curve illustrating the physical properties resulting from two types of tests conducted on clay soil from the Serang-Panimbang Toll Road: soil samples with initial field density and soil samples with maximum density. The impact of drying-wetting on the soil physical properties is observable in the fluctuations, showcasing both increases and decreases in property values.



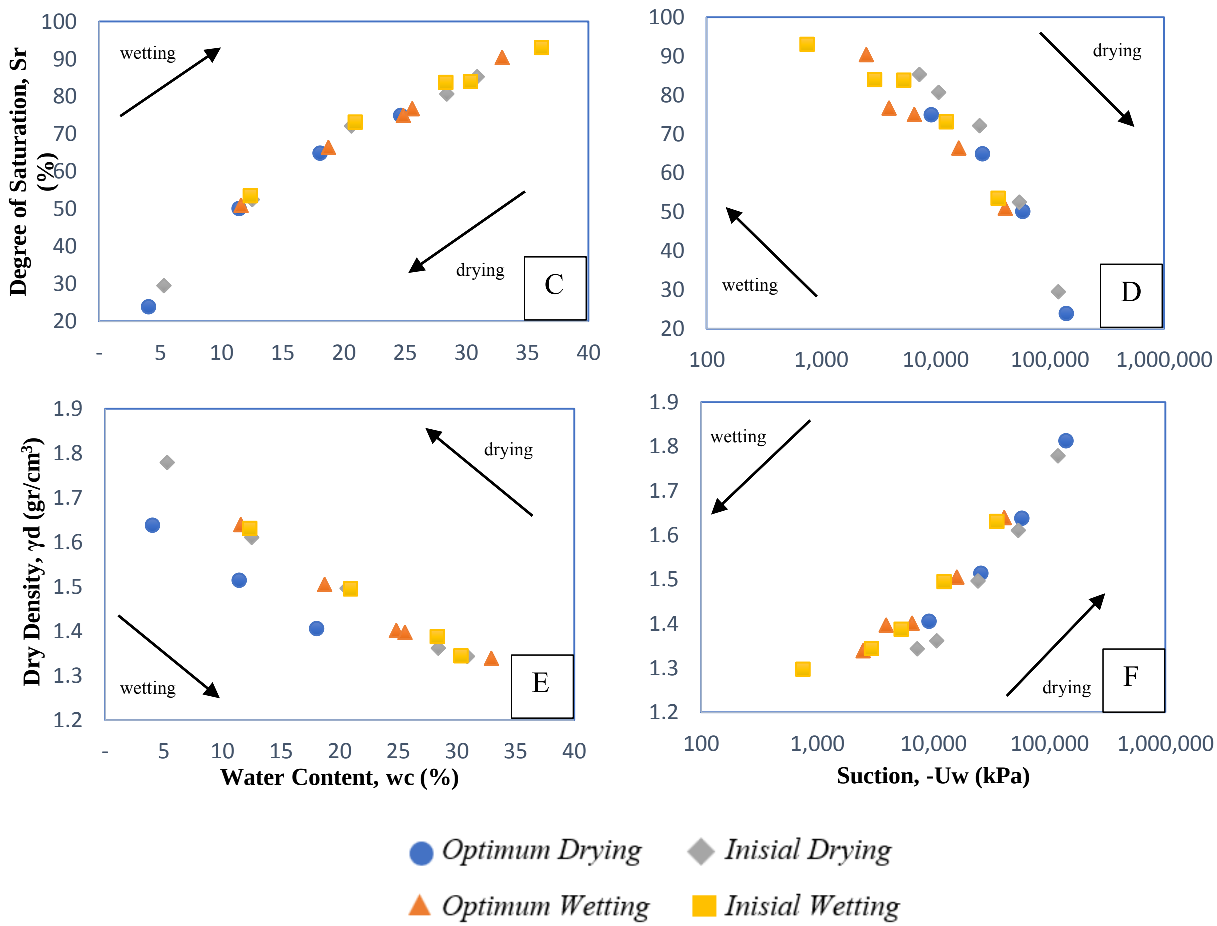


Figure 3. Comparison of Drying-Wetting on the Physical Properties of Clay Soil on the Serang-Panimbang Toll Road under Initial and Maximum Density Conditions

Influence of Drying-Wetting on the Parameters of Soil Mechanical Properties

(e)ISSN 2656-8896 (p)ISSN 2656-890X
Journal of Infrastructure and Facility Asset Management – Vol. 6,Special Issue 2, January 2024

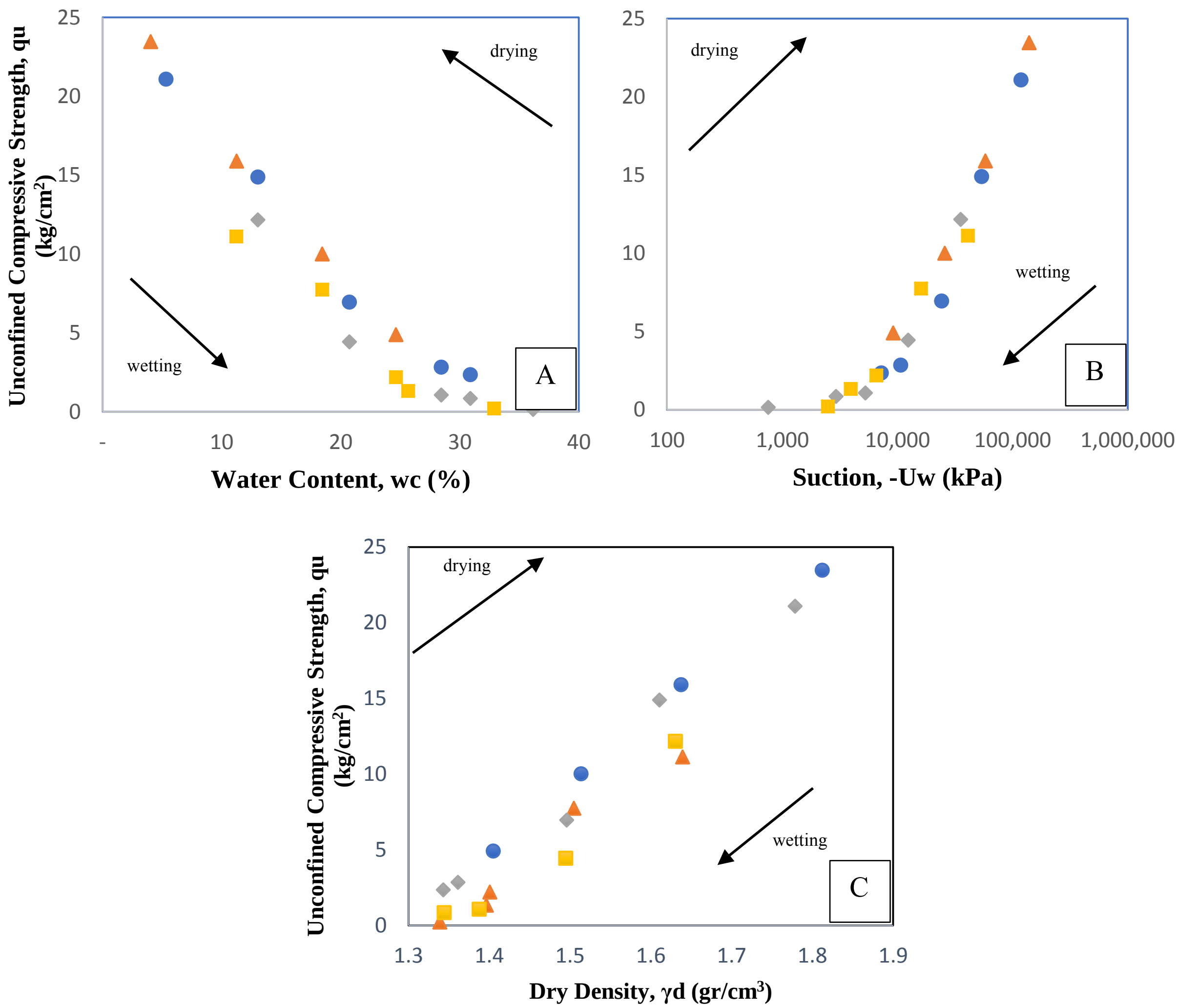


Figure 4. Comparison of Drying-Wetting on the Mechanical Properties of Clay Soil on the Serang-Panimbang Toll Road under Initial and Maximum Density Conditions

Based on **Figures 3 and 4**, it can be concluded that after undergoing one cycle of drying and wetting tests on soil with initial field density and soil with maximum density, the dry density of soil (γ_d) and unconfined compressive strength (qu) decreased, while the void ratio (e) increased. The reduction in dry density (γd) of the initial soil was 3.43%, and for the soil with maximum density, it was 4.71%. The decrease in unconfined compressive strength (qu) for the initial field density soil was 93.45% (from very stiff consistency to very soft), and for the soil with maximum density, it was 95.82% (from hard consistency to very soft). The increase in void ratio (e) for the initial field density soil was 6.81%, and for the soil with maximum density, it was 9.67%. When water content (wc) increases, the dry density of the soil (γ_d) decreases. The worst soil condition occurs when it's saturated, resulting in reduced contact between soil particles, leading to decreased soil compaction, thereby reducing the unconfined compressive strength (qu) and increasing the void ratio (e).

Soil - Water Characteristic Curve (SWCC)

Soil - water characteristic curve (SWCC) is a function of the ratio between volumetric water content (θ) and suction. Where the volumetric water content (θ) is obtained from the degree of saturation multiplied by the pore volume and divided by the soil volume.

Suction value is a function of the capillary pipe phenomenon. During wetting water fills the pore on soil and the diameter of pore wil enlarges. The larger the radius of the capillary tube (d), the smaller the surface tension and the consequently smaller the suction. To obtain the suction value, soil suction testing was carried out with the filter paper method (ASTM D 5298-03) using whatman filter paper no. 42 with the equation in the Filter paper water content graph, Wf (%) versus Suction (kPa).

From the results of the drying-wetting test, the suction matrix or Soil-water characteristic curve (SWCC) of the Serang-Panimbang Toll Road clay soil is obtained with two conditions, soil conditions with initial field density and soil conditions with maximum density shown in **Figure 5** below.

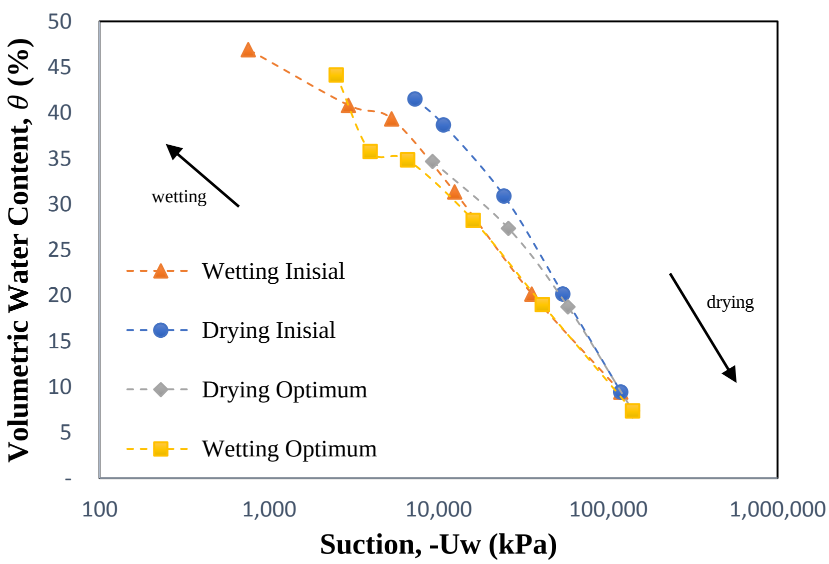


Figure 5. SWCC under Initial and Maximum Density Conditions

The implementation of the drying-wetting cycle led to an elevation in suction (-Uw) as the volumetric water content (θ) decreased. The volumetric water content, expressed as θ (%), impacts the magnitude of suction, -Uw (kPa), given that θ represents the ratio between water volume and soil volume. Hence, the volumetric water content (θ) is significantly influenced by the soil water content (w), wherein fluctuations in water content induce alterations in pore, affecting the suction within the soil.

Previous research has also demonstrated an augmentation in suction (-Uw) with a reduction in volumetric water content (θ) according to the SWCC curve. In this current study, it is evident that the suction (-Uw) value of the soil with maximum density surpasses that of the soil with initial field density. This suggests that the soil with maximum density experiences a lesser impact drying-wetting process compared to the soil with initial density.

(e)ISSN 2656-8896 (p)ISSN 2656-890X
Journal of Infrastructure and Facility Asset Management – Vol. 6,Special Issue 2, January 2024

Influence of Drying-Wetting on The Erodibility

Variations in soil erodibility values were determined based on the Wischmeier nomogram, which heavily relies on four parameters: organic content, soil structure, soil texture, and soil permeability. Drying-wetting tests were conducted using the same soil type but under different conditions, encompassing soil samples with initial field density and soil samples with maximum density. Following these drying-wetting tests, permeability coefficient result were derived utilizing the empirical formula by Campbell (1973). These results were based on the volumetric water content and suction parameters obtained from the gravimetric suction and volumetric tests. As a result, distinct permeability coefficient values were obtained, all falling within the class 6 category according to the Wischmeier nomogram, with a permeability value <0.5 cm/hour.

Table 5. Erodibility Parameters

Parameters	Value/Class	Information
Percent Silt + Very Fine Sand	**41,20 %**	Form Sieve Analysis
Percent Sand	**8,708 %**	Form Sieve Analysis
Soil Organic Content	**1**	Obtained from the results of testing soil organic content with Walkley & Black Method (1934)
Soil Structure	**1**	Form Sieve Analysis
Soil Permeability	**6**	From Campbell Formula (1973)

Source : Author, 2024

Once these parameters are obtained, they are inputted into the Wischmeier nomogram, resulting in an erodibility value of 0.19 for all drying-wetting cycles, from the initial condition to the saturation point. The graph illustrating the erodibility values shown in Figure 6 below.

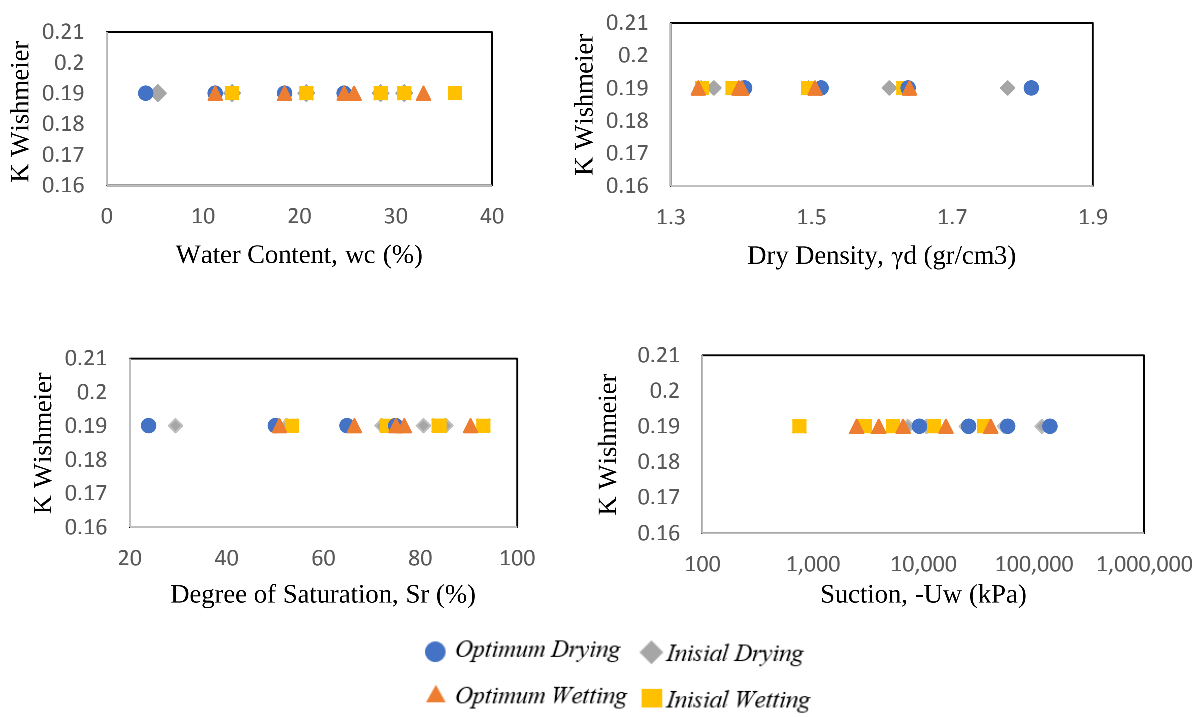


Figure 6. Correlation between Soil Density and Erodibility

Figure 6 shows that the effect of erodibility value does not occur in the drying-wetting test of clay soil of Serang-Panimbang Toll Road. Although with different soil densities, that is field density and maximum density and physical properties such as changes in water content (w) from 4.04% to 36.19%, dry volume weight γd from 1.343 gr/cm^3 to 1.813 gr/cm^3, degree of saturation (Sr) from 23.93% to 93.06% and suction (-Uw) have no effect on the constant erodibility value of 0.19, where based on the class for the value of erodibility is included in the low category.

The effect of drying-wetting on soil erodibility parameters that are dominantly influenced by the value of the permeability coefficient shows no change because changes in water content do not make the permeability class value change. With the clay soil category, the average value of the permeability coefficient is at 0.000001 cm/sec (Das, 1995) which will directly fall into class 6 in the permeability class that determines the erodibility value.

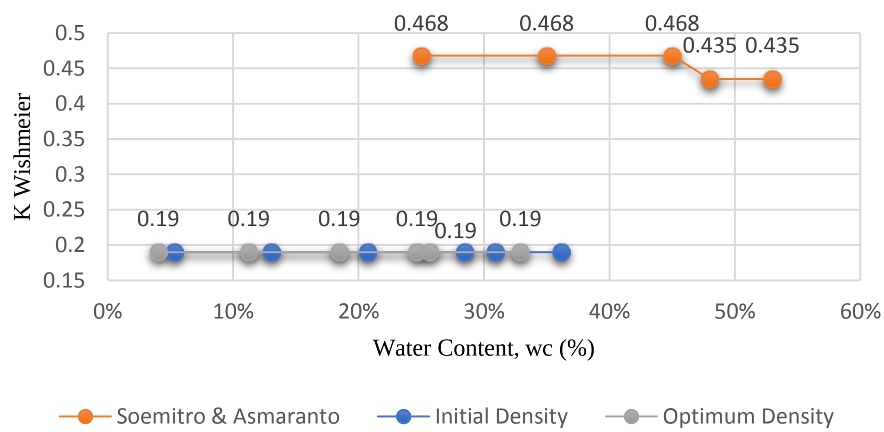


Figure 7. Comparison of Erodibility Values with Previous Research

Figure 7 shows this research is almost in line with previous research from Soemitro & Asmaranto (2016), the effect of drying-wetting to the Wischmeier soil erodibility factors shows the effect of wetting-drying on soils with the ML category, namely inorganic silt soil with low plasticity, also does not look significant. The erodibility value changes starting from water content above 45% with an erodibility value (K) of 0.435. While for water content from 15%-45% the erodibility value is constant at 0.468. This research also conducted a wetting-drying test on the erodibility value but with a different type of soil, namely soil with CH classification where this type of soil is an organic loam soil which does have a very small permeability coefficient value compared to other types of soil. Then for the maximum or saturated water content is only at a maximum value of 36.17% which makes the erodibility value unchanged with a constant value of 0.19 every interval of change in water content from initial conditions to water saturated conditions (w_{sat}).

CONCLUSIONS

1. Based on the physical and mechanical properties tests that have been carried out, it is known that the initial soil classification on the Serang-Panimbang Toll Road is included in CH (Fat Clay) according to USCS and soil type A-7-6 according to AASHTO. The water content (w) is 30.90%, the void ratio (e) is 0.946 and the dry density (γ_d) is 1.344 gr/cm^3. The plasticity index value is 43.91%. As for mechanical properties, the unconfined compressive strength (qu) value is 2.35 kg/cm^2.

2. The drying-wetting test caused changes in the physical and mechanical parameters of the clay soil with initial density or field density conditions, where there was an increase in the void ratio (e) by 6.79% and the degree of saturation (Sr) by 8.31% from the initial condition to the saturated condition. Conversely, there was a decrease in the dry density (γ_d) by 3.43%. Meanwhile, there was a change in the consistency of unconfined compressive strength from very stiff to very soft.
3. The drying-wetting test caused changes in the physical and mechanical parameters of the soil under maximum density conditions, where there was an increase in the void ratio (e) by 9.65% and the degree of saturation (Sr) by 17.12% from the initial condition to the saturated condition. On the other hand, there was a decrease in the dry density (γ_d) by 4.69%. Then for mechanical properties based on the unconfined compressive strength value decreased by 95.91% where the consistency changed from hard to very soft.
4. From the drying - wetting tests that have been conducted on the erodibility of clay soil on the Serang-Panimbang Toll Road, it shows that there is no visible change in the erodibility (K) 0.19 which is included in the category of having low erosion. This is because the parameter to determine the erodibility value is dominantly influenced by the permeability coefficient. In this wetting-drying test, the permeability coefficient does not change as the water content changes because clay soil does have a very small coefficient value compared to other types of soil.
5. From the results of the drying - wetting test with two samples of test specimens, namely soil with initial density and soil with maximum density did not cause changes in erodibility values. The effect of soil density is not seen in this test because the soil type is included in the CH classification where the permeability coefficient value is also very small and the water content in its saturated condition which is only worth a maximum of 36.19% does not make the erodibility (K) change and remain constant.

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